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Erosion Control on Air Force Bases

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25

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FOREWORD

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This technical note has been reviewed and is approved.

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ABSTRACT

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A state-of-the-art review of the soil erosion field as it relates to the erosion control needs of the US Air Force was conducted. The review will serve as a guide for preparation of a Base Civil Engineer erosion control handbook. Typical military construction activities which have exposed large areas of unprotected soil and subsequently have led to serious erosion problems are presented. Factors involved in the wind and erosion processes are discussed and soil-loss equations and soil erodibility indices are reviewed. The erodibility K-factor in the ARS soil-loss equation is evaluated for land management planning techniques. Guidelines for effective erosion control practices to protect exposed land surfaces against soil particle detachment and transport by either water or wind are presented. Further efforts to establish a more reliable erodibility index which can be used to define areas of highly erodible soils, especially for subsurface soils that are exposed during construction are indicated.

CONTENTS

SECTION I
INTRODUCTION

The Air Force Weapons Laboratory (AFWL) of Air Force Systems Command was designated in early fiscal year 1967 as the lead laboratory for Air Force civil engineering exploratory and advanced development efforts. As a part of the assigned mission, AFWL personnel visited South Vietnam and Thailand to obtain soil samples for use in a study of the applicability of structural stabilization. During this visit, severe wind and water erosion was observed on many Air Force installations. During the build-up in Southeast Asia (SEA) the extensive construction exposed large areas to erosion by the intense monsoon rainfall and strong winds. Coastal installations were especially subject to wind erosion of the beach sands; the construction of earth revetments and other structures created steep unprotected slopes which were easily eroded. The erosion effects were unsightly, damaging to the facility and its operational effectiveness, destructive to drainage systems, and caused increased maintenance and management costs. Discussions with the Base Civil Engineering personnel indicated that there was little guidance for them to follow in attacking the erosion problems. In view of this, AFWL initiated an effort to develop the information required to prepare a field handbook on erosion control for Air Force Base Civil Engineers. The handbook would be for use in areas such as SEA where information often is not readily available.

A contract was awarded to Water Resources Engineers, Inc. (WRE) of Walnut Creek, California, in January 1969 to develop the erosion control information. The objective of this study was to assemble and evaluate existing knowledge on the control and prevention of soil erosion. It was hoped that a laboratory effort could be accomplished during the study to determine relationships between the engineering properties of soil and erosion; however, this effort was limited to a review of erosion prediction equations and erodibility indices. Since most Air Force personnel at Theater of Operations installations are Civil Engineers, a relationship establishing erodibility based on an easily obtained engineering soil property would allow for more effective evaluation of a site's erosion potential and the establishment of an erosion control program. The research contract was completed in June 1970 and the results will be published in AFWL-TR-70-54, A Guide to the Development of an Air Force Erosion Control Manual (Ref 1). This paper primarily presents the results of the WRE contract.

SECTION II
GENERAL ASPECTS OF SOIL EROSION

Soil erosion is defined simply as the detachment and relocation of soil particles through the abrasive action of wind, water, ice, and gravity. The focal point of this discussion is accelerated erosion induced by such human activities as agriculture, urban development and construction of highways, airports, and military bases. Because the erosional processes and resulting sediment products characteristically developed at these sites are local in extent, a detailed account of sedimentation in rivers and reservoirs is not presented. However, the intensity of localized erosion and deposition can present a substantial impediment to the human activity which first created the potential erosion site through disturbance of the soil cover.

Erosion by water occurs as sheet erosion on overland surfaces and as channel erosion under concentrated surface runoff conditions. Sheet erosion is usually associated with the removal of uniform soil layers through the detaching force of raindrop splash and the transporting capability of overland flow. The formation of rills signifies the concentration of overland flow and marks the transition from sheet erosion to the channel erosion process. Channel or gully erosion normally develops from the accelerated erosion of rills and other depressions of the surface which tend to concentrate surface runoff. Thus, channel erosion is produced by the detaching and transporting forces of concentrated flow. The intensity of all erosion processes is strongly dependent on the inherent susceptibility of soil particles to detachment transport--a property referred to as soil erodibility.

Wind is a primary erosion and sediment transport agent in arid or semi-arid regions and along seacoasts. Factors affecting the intensity of wind erosion include wind speed and direction, surface roughness, topography, soil texture and structure, and moisture content.

Gravity erosion results when the weight of the soil mass exceeds the frictional resistance or shear strength of the soil. Examples of this erosion process include landslides, back sloughing, talus movement, and mud flows. The influence of cut and fill operations and other construction practices is a major factor in gravity erosion. Water usually plays an extremely important role through reduction of toe support and shear strength in the gravity erosion process.

Climate exerts a profound influence on the erosion of soil by wind and water. Not only does climate control the type and intensity of the erosion processes through the actions of wind and water, but it also largely determines the resistance of eroding materials through the process of weathering and resultant formation of parent soil material.

Similarly, climate is a dominant factor in the determination of vegetative cover which is an important factor in the erosion process. The success or failure of selected erosion prevention and control techniques can be directly influenced by climatological factors affecting both the growth of vegetative controls and the efficiency of mechanical control devices.

1. MECHANICS OF WATER EROSION

The water erosion process takes place in three distinct phases--detachment, transportation, and deposition of the soil particles. The principal erosive agents are rainfall and surface runoff, which may act independently or in combination. Raindrop splash is the primary detaching force on uniform land surfaces, while surface runoff serves as both a detaching and transporting agent in rills and gullies. The complementary nature of the two erosive agents is most obvious during sheet erosion when raindrop impact induces turbulence in surface runoff and thereby increases its capacity to detach and transport soil particles.

The major factors determining the resulting water erosion can be categorized under four areas--soil, slope (topography), vegetation, and rainfall. The rainfall provides the detachment and transport medium; variables of importance include the rainfall duration, intensity, drop size, and kinetic energy. Investigations of soil erodibility have indicated many physical-chemical soil properties that are related to erosion--including adsorptive capacity for water, permeability, size and shape of particles, degree and stability of aggregation, ease of dispersion, organic matter content, and moisture content. The degree and length of the slope are the primary factors of topography affecting runoff and erosion.

Vegetative factors of significance in both water and wind erosion processes are the type, density and condition of ground cover which modifies the effect of precipitation or wind on the soil surface and profile. The vegetative influences vary with the season, kind of vegetative material, degree of maturity, soil, climate, and management.

2. MECHANICS OF WIND EROSION

In a manner analogous to that for water erosion, the process of wind erosion can also be reduced to three fundamental sub-processes consisting of particle detachment, transport, and deposition. The critical or threshold conditions under which soil movement is initiated has been the subject of intensive wind-tunnel and other laboratory experiments. Chepil (Ref 2) and Chepil and Milne (Ref 3) found that the most significant factor influencing the threshold velocity of any soil is the size of the soil grains. This critical velocity is a minimum for particles between 0.1 and 0.15 millimeters (mm) in diameter.

The movement of soil by wind takes place in three ways. Saltation is the term used to denote the bouncing movement of particles within a layer close to the ground surface. On striking the ground, a saltating soil particle may rebound and continue its movement as before, or it may strike a particle at rest and cause it to rise. The soil grains most susceptible to saltation range from 0.1 to 0.5 mm in diameter and these may reach heights of one to two feet. A second transport process known as surface creep is induced by the impact of particles descending from saltation. Soil grains having diameters of from 0.5 to 1.0 mm are too heavy to be moved by saltation, but are pushed along the surface by the impact of particles in the sliding, rolling movement of surface creep. A third wind transport process moves soil particles having diameters less than 0.1 mm by a process known as atmospheric suspension. In this process, fine soil particles are lifted into the turbulent air stream and may be carried large distances. After being lifted from the ground surface and transported by the air stream, soil particles are eventually deposited whenever the velocity and turbulent structure of the wind becomes incapable of further transport.

The three major factors controlling wind erosion are the characteristics of the wind and soil and the nature of the soil surface. The erodibility of soil by wind is primarily determined by soil texture, structure, and stability in a dry condition. According to Chepil (Ref 4) a simple but effective index of soil erodibility is the proportion of soil fractions greater than about 1 mm in diameter, as determined by dry sieving. Soil particles with diameters less than 1 mm are generally considered erodible, while soils resistant to wind erosion contain at least two-thirds by weight of fractions greater than 1 mm.

SECTION III
SOIL-LOSS EQUATIONS AND SOIL ERODIBILITY INDICES

The distinction between an erodibility index and soil loss equation lies primarily in the fact that the latter deals with the problem of estimating sediment yields or soil losses from natural and undisturbed areas. Thus, the soil loss equation includes parameters representing both the internal properties of soils and the external influence of rainfall, overland slope, land management practices, and surface cover conditions. The soil erodibility index, on the other hand, refers only to the inherent physical-chemical properties of the soil which cause one area to be more susceptible to the erosive forces of wind and water than another area exposed to similar environmental conditions. Thus, the soil erodibility index is an essential factor in the soil-loss equations.

In the absence of general laws governing the erosion of in situ soils, investigators searching for reliable erodibility indices and soil-loss equations have been forced to rely on largely empirical methods. Efforts to date have been directed at the formulation of soil erodibility relationships by statistical correlation techniques which require a large supply of local survey and laboratory data. The resulting expression is usually restricted to the particular field conditions encountered in the sampling program and then it yields an estimate of relative soil erodibility based on some set of soil and field conditions. The largest portion of this work has been done by the Soil Conservation Service, the Agricultural Research Service (ARS), and the Forest Service of the USDA for reducing agricultural and forest soil losses through improved erosion control and land management practices.

Although many equations have been developed, the universal soil-loss equation developed by ARS for predicting rainfall erosion losses from humid climate farm lands is probably the most versatile (Ref 5). The equation is an empirical relationship between soil-loss for a given storm per unit area and all major factors known to influence rainfall erosion. It has the form:

$$A = R\ K\ L\ S\ C\ P$$

where

A = computed soil loss, tons/acre

R = rainfall erodibility index, foot ton inches/acre hour

K = soil erodibility factor, tons/acre

L = slope length factor

S = degree of slope factor

C = cropping management factor

P = erosion control practice factor

The rainfall factor, R, is defined as (Ref 6):

$$R = \frac{EI}{100}$$

where E = total kinetic energy of a given storm

I = the max 30 minute rainfall intensity

The rainfall factor is a product term representing the effects of raindrop impact for the entire storm duration and maximum rainfall intensity. The factor can be expressed as a function of rainfall intensity alone using the equation determined by Wishmeier and Smith (Ref 7): $E = 916 + 331 \log_{10} I$

where I = rainfall intensity, inches/hour

The soil erodibility factor, K, represents the inherent erodibility of soils and is determined experimentally as the ratio of erosion per unit of R from a unit plot on a particular soil. A unit plot is 72.6 feet long, has a uniform slope of 9 percent, is kept in a continuous fallow condition and is tilled up and down the slope. When all the conditions of a unit plot are met, each of the factors L, S, C, and P equal unity and $K = A/EI$.

Although the effects of slope length and degree on soil loss have been investigated separately, they are usually combined in a single factor, LS. LS is the ratio of soil loss per unit area from a given field to that from a unit plot. The combined LS factor can be computed from the empirical equation:

$$LS = \lambda^{0.5} (0.0076 + 0.0053S + 0.00076S^2)$$

where λ = field length, feet

S = dominant slope, percent

The cropping management factor, C, is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from tilled, continuous fallow. The erosion control practice factor, P, is a parameter representing the reduction in soil loss resulting from soil conservation measures such as contour tillage, contour strip cropping, terracing, and stabilized waterways.

The soil loss equation was developed to provide a general guide for the selection of soil and water conservation practices on croplands. The equation can be solved for specific conservation practices, given known soil-loss tolerances, although this procedure is tempered by subjective evaluation in most field applications. Thus, while the soil-loss equation attempts to quantify many factors associated with the rainfall-erosion process, it remains a completely empirical device requiring subjective interpretation by the user.

The value of the soil-loss equation as a planning tool lies primarily in the fact that it represents a concise historical summary of agricultural erosion data recorded since 1939 in many parts of the US. Its utility is restricted partially be the absence of bench-mark K-values for soil conditions which fall outside the limits of the investigations conducted by ARS. Thus, the soil-loss equation is not strictly applicable to certain non-cropland erosion conditions of interest to the Air Force. Such conditions include large air base construction sites at which disturbed sub-soils and surface soils are exposed to the erosive forces of wind and water.

Many factors have been investigated for possible use as an index of a soils inherent susceptibility to erosion by rainfall and runoff. Several recent studies have been directed at the evaluation of the K-factor in the ARS universal soil loss equation for representing inherent soil erodibility. Wischmeier and Mannering (Ref 8) have computed K directly from soil-loss occurring under simulated rainfall on 55 medium textured soils in the corn belt region of the US. These computed K-values were then related, by means of step-wise multiple regression, to physical-chemical properties of the soil which were thought to influence soil detachment and transport. Properties that contributed significantly to soil-loss variance included percentages of sand, silt, clay, and organic matter, pH, structure and bulk density of the plow layer and subsoil, slope steepness and profile, pore space filled by air, residual effects of sod crops, particle aggregation, parent material, and various combinations of these variables. The K-factor was the most sensitive to changes in organic matter content, water-stable aggregation, and mechanical analysis.

Wind erosion equations have been developed for the purpose of evaluating the erodibility of an entire field surface exposed to the detaching and transporting forces of wind. The development and application of such equations has not received as much emphasis as equations for predicting erosion by water. A universal wind erosion equation has been developed by ARS (Ref 9) for use in the Great Plains of the US. The equation is:

$$E = I\ R\ K\ F\ C\ W\ D\ B$$

where E = soil loss, tons/acre

I = an erodibility index based on percent of soil particles greater than 0.84 mm in diameter

R = crop residue, pounds/acre

K = ridge-roughness factor, inches

F = index of soil texture and its relative stability

C = geographic location factor reflecting difference in wind velocity and surface soil moisture

W = width of field

D = wind direction factor

B = wind barrier index representing field protection by shelter belt or tall vegetation

The two best indices of soil erodibility have been indicated by Chepil (Ref 10) as: (1) the state of the dry soil structure defined by the percentage of non-erodible aggregates greater than 0.84 mm in diameter as determined by dry sieving and (2) the stability of the dry soil structure or its resistance to disintegration. In general, particles greater than 0.84 mm are considered non-erodible by wind.

SECTION IV
EROSION CONTROL AND PREVENTION

1. PRINCIPLES OF WATER EROSION CONTROL

With respect to rainfall forces, the object of control practices is to protect exposed land surfaces against particle detachment and transport resulting from raindrop impact--using either natural or artificial ground cover. These control practices induce infiltration, retard surface runoff and generally conserve soil moisture. In the case of erosion by surface runoff, the immediate objective of most control practices is to retard the velocity and concentration of overland flow and thereby reduce its capacity to detach and entrain eroded materials. To be the most effective, erosion control practices must be preventive rather than remedial.

A variety of principles and practices can be applied to the control of erosion by rainfall and runoff. The choice of method depends on the specific nature of the on-site erosion hazard and the magnitude of economic damages generated by the erosion process. In so-called non-critical erosion areas having good soils and moderate slopes, the use of vegetative practices is preferred for reasons of economy and long term land stability. In regions of steep slopes and unstable soils where erosion problems have reached critical proportions, the use of more expensive mechanical or structural control techniques may be justified. The design life of temporary bases in the Theater of Operations may not permit the establishment of vegetative ground cover. Consequently, the application of mechanical and structural erosion control measures may be required to maintain the operational readiness of the base.

All water erosion control methods fall basically into one of three broad categories designated as vegetative, mechanical and structural measures. Vegetative practices include the use of natural ground covers such as grasses, shrubs and trees. Mulches that provide temporary soil stability while permanent vegetative cover is established may in some cases be considered vegetative. Vegetative treatment protects against erosion in four important ways: (1) plant materials intercept rainfall and minimize the effect of raindrop impact, (2) it promotes infiltration and thereby reduces the amount of rainfall available for runoff, (3) the extensive root system helps to bind the soil and make it more resistant to erosive forces and (4) vegetation increases the roughness of the ground surface which retards the velocity of overland flow.

Mechanical control practices are most often used in conjunction with vegetative practices. Some artificial mulches may be considered mechanical. Rough tillage, contour farming, furrowing, and strip cropping are common agricultural mechanical erosion control practices.

Gradient terraces, level terraces, diversions, grassed and lined waterways, and grade stabilization structures are measures that might be considered both mechanical and structural. Mechanical practices are used primarily to convey excess surface water away from erodible areas.

Structural measures are used for land stabilization, stream flow regulation, and water sediment storage. Major structural controls commonly in use include: (1) reservoirs, both detention and multipurpose, (2) stream channel improvements, (3) debris and sedimentation basins and (4) levees and dikes.

Air Force Manual 85-6 (Ref 11) divides vegetative treatments into perennial grasses and legumes; annual cover; trees, shrubs and vines; and mulches. Perennial grasses and legumes are especially effective and adaptable since permanent vegetative cover can be provided over a wide range of soil and climatic conditions. The use of vegetative treatment with grasses requires the selection and use of grasses best adapted to the soil and climatic condition of the area. Annuals may be used for temporary control or as an aid for establishing permanent cover. Trees, shrubs, and vines may be used to provide erosion protection on steep rough areas, embankments, and non-use areas as well as for providing windbreaks and sound abatement barriers.

Mulches may be used alone or in combination with the establishment of vegetation. Mulches include straw, hay, gravel, woodchips, asphalt emulsions, and other similar materials. Mulches are often used in combination, for instance hay and asphalt emulsion with the asphalt being used to anchor the hay to the soil surface. There are many commercial materials available which are classified as mulches. Careful evaluation of the erosion control requirement should be made when selecting a commercial product for use. Many highway departments and other agencies have evaluated various mulches and this information should be considered. The commercial mulches available include many liquid chemical and petroleum products, wood cellulose fibers, fiberglass filaments, various types of mats and nets and wood excelsior.

Organic mulches such as hay normally are used as a protective surface cover and anchored either by disk packing or by asphalt emulsion. This type of mulch also increases infiltration and reduces evaporation. Some of the commercial products available will also provide protection similar to the natural materials such as hay. There are chemical mulches available that provide some degree of bond between the soil particles to make the soil more resistant to both water and wind erosion. It is desirable to obtain good penetration of these materials into the soil. Some materials are available for use which provide an impervious cover on the soil surface. These materials are the most useful in the control of wind erosion and on steep embankments.

Mechanical-structural control measures for use on air bases include terraces, diversions, grassed waterways, and grade stabilizing structures. Descriptions of these various methods will not be given here. Guidelines for design and construction are available in AF drainage manuals and Soil Conservation Service publications. In most cases, these types of control practices are to provide control and conveyance of surface runoff.

Structural erosion control measures of interest to Base Civil Engineers include: small flood control dams, dikes and levees, stream channel improvements and bank stabilization, sediment basins and outfall structures. Sediment basins may become of considerable importance as a control for pollution by sediment from Air Force installations. The engineering handbooks of the Soil Conservation Service are a good source for information on design and construction of erosion control structures.

Steep slopes and gullies present special erosion control problems. On slopes vegetation may be effective; however, if the slope is excessively steep or long and is subjected to excessive overland flow, erosion will occur. Practices to divert or substantially decrease the overland flow may provide the necessary control. Proper selection and establishment of vegetation on steep slopes will provide erosion protection if properly maintained. On some short steep embankments an impervious mulch may be the most effective control, if the increased surface runoff can be adequately handled.

Vegetative, mechanical, and structural measures may be used independently or in combination for gully erosion control. Gully control can best be attained through a plan that takes into account the treatment of the watershed draining into the gully, as well as the treatment of the gully itself. The plan may include such practices as critical area plantings, grassed waterways or outlets, grade stabilization structures, diversions, and debris basins. These practices may be used singly or in combination with other practices to principally accomplish: (1) interception of runoff water above the gullied area with a diversion or terraces, (2) retention of runoff water on the drainage area by tillage, vegetation, or structures, (3) elimination of the gully by filling or shaping the drainageway for critical area planting or grassed waterway development, (4) revegetation, either by natural processes, by critical area planting or grassed waterway development, (5) construction of grade stabilization structures to control the grade of the gully and detain or impound water, and (6) control of sediment from active gullies with sediment basins.

Of special importance in the Theater of Operations is the severe erosion that occurs on cleared and graded areas during periods of rapid construction when permanent seeding is not practical. Supporting erosion control practices such as contour furrows, terraces and sediment basins along with surface mulching or a combination of surface mulching and temporary vegetation can check excessive erosion. Surface treatments with chemical mulches may also provide the required temporary erosion protection.

2. PRINCIPLES OF WIND EROSION CONTROL

Dust, blowing soil, and migrating sand dunes constitute significant erosion hazards at Air Force installations where the operational efficiency of aircraft engines, sensitive instrumentation, as well as the safety and morale of personnel may be jeopardized by lack of effective control measures. In addition, runways, operational facilities and residential areas may be subjected to possible physical damage. Uncontrolled dust clouds raised by aircraft and vehicular operations can present tactical problems in a combat zone.

While almost any soil will blow under certain physical conditions, the soil conditions most conducive to wind erosion are a smooth, finely pulverized surface free from a living vegetative cover. With these basic aspects of the wind erosion process in mind, the principles of wind erosion control can be stated as:

(1) Protect erodible soil surfaces directly with a surface cover consisting of natural vegetation, where environmental conditions favor its growth, or an artificial material which provides temporary stability until a permanent vegetative cover can be established.

(2) Roughen the soil surface to reduce wind velocity and thereby greatly reduce the capability of wind to detach and transport erodible soil materials.

(3) Improve soil aggregation by means of chemical soil conditioners and stabilizers which produce aggregates of sufficient size to resist transport by wind.

(4) Install barriers such as windbreaks and shelter belts directly in the path of prevailaing winds to trap, store and stabilize drifting soils and sand dunes. A wide variety of control practices are available using the above principles. Selection of a control practice depends both on the length of time available for arresting the wind erosion problem and on the specific nature of the site to which the problem is confined.

The measures for controlling wind erosion can be classified as vegetative, including the use of grasses, shrubs, trees, and other ground covers, or they may be mechanical measures such as wind fences and barriers. The practices may also be classed as permanent or temporary. The amount of traffic and artificial disturbance, such as jet blast, an area receives must be carefully considered. The establishment and maintenance of permanent protective cover should be the ultimate objective for a successful wind erosion program.

Permanent control measures include long-lived vegetative covers, wind breaks and shelter belts, and permanent mechanical treatments such as crushed rock and gravel. Permanent grass covers are the most satisfactory long time solutions for most wind erosion problems. Careful attention must be given to the selection and establishment of the most suitable grass and/or legume under the adverse field conditions encountered on most wind erosion areas. Newly planted materials and seedlings must be given temporary protection against sand blast, blow out and deposition. The most satisfactory method is to provide suitable protection to check the wind, improve soil fertility and provide the best possible soil moisture conditions during the critical period of establishment. Windbreaks and shelter belts have trees and shrubs planted in an organized pattern so as to reduce the wind velocity at ground level. They also serve as a sediment barrier, modify air and soil temperatures, reduce evaporation, and assist in protecting newly seeded areas. The three most common permanent mechanical treatments are crushed rock and gravel, Portland cement concrete, and asphaltic concrete, These materials have the advantage of not deteriorating over a considerable length of time; however, they are costly to apply.

Temporary measures must often be used when existing wind control measures fail or an area is cleared during construction in an area where soil blowing is a problem. Temporary measures usually are emergency expedients to provide immediate protection or are used as the initial operation in the establishment of permanent stabilization. The following are some of the more common temporary measures: rough tillage to provide a rough cloddy surface, quick growing annual cover crops, organic mulches, mechanical barriers such as silt fences, prefabricated membranes and meshes, bituminous soil surface treatments, resin soil conditioners, salts, and other miscellaneous materials.

A number of commercial emulsions, mulches, erosion control blankets, lightweight membranes, and filter blankets have recently been evaluated for dust control in tactical operations by the US Army Engineer Waterways Experiment Station (Ref 12).

Sand dunes are a special case of wind erosion which occurs on Air Force installations. A sand dune is a mound or ridge of wind-blown sand material which develops in response to wind stresses in arid coastal or inland regions. Sand dunes may develop as: (1) flat sand sheets in barren areas under constant [illegible] winds; (2) fixed

dunes resulting from the accumulation of sand adjacent to hills, cliffs, buildings and other immovable obstructions; and (3) moving sand dunes occuring in large regions of loose sands and sparse vegetation.

The methods of controlling sand dune migration include placement of mechanical barriers, chemical surface treatment and vegetative stabilization. Appendix II, Chapter 3, of Air Force Manual 88-17 provides general guidelines for control of sand dunes. The control measures can again be classified as either permanent or temporary--vegetative control measures being the only broad class of treatment qualifying as permanent. However, optimal treatment by vegetative controls usually requires the conjunctive application of temporary dune stabilizers. In most cases the vegetation must be drought resistant and adapted to the climate and soil. To cut off new sand while vegetation is being established, methods such as the following may be used: slated fencing, solid panels or fencing, bituminous, resin and other chemical materials, mulches and membranes, water, mechanical removal, and trenching.

3. APPLICATION OF SOIL EROSION CONTROL PRINCIPLES AND PRACTICES

Erosion prevention and control problems on US Air Force bases should be approached from the standpoint of optimal use of existing information and technical assistance available within and outside the Air Force. All the available resources should be used whether the problem is one of research, planning, installation or maintenance of conservation practices. WRE illustrated the principles and practices of erosion prevention and control with the development of an erosion control and maintenance plan for Travis Air Force Base, California.

The best experience in developing sound erosion and related soil and water conservation programs lies in a two fold system for mapping, describing and interpreting the physical, chemical, and biological properties of the land, according to the best scientific and engineering methods and the formulation of a coordinated land use and treatment plan with a layout map of practices and a schedule for timing the application of practices. The first part of this approach has been commonly referred to as the soil survey and land capability interpretations carried out by the Soil Conservation Service. It includes consideration of underlying weathered geologic formations; soil properties; the type and condition of the existing vegetation, the climatic influence; the slope percent and length, and the type and degree of previous erosion. After mapping the properties and influences, the entire array of land and water facts must be subjected to interpretative study to plan for optimal land use. The next step is to determine the best erosion control treatments for each area, including limitations on the intensity of land use.

A proposed wind and water erosion control manual for Air Force Base Civil Engineers was outlined by WRE. The outline is intended to present general information on existing techniques of erosion control for the use of Base Engineers located at remote sites. A general manual as outlined cannot supplant a detailed technical erosion control guide prepared for the specific environment of a local Air Force Base by a qualified soils engineer or agronomist. Nevertheless, the outline recommended presents a method of attack by which the non-specialist Base Civil Engineer in a remote site can become familiar with the techniques of wind and water erosion control and thereby initiate an intelligent erosion control program.

SECTION V
SUMMARY AND RECOMMENDATIONS

In general, the state of the art in water and wind erosion control has progressed not through the establishment of general laws which dictate the respective processes, but rather through the accumulation of empirical observations generated by numerous laboratory investigations. From these observations have emerged rule-of-thumb guidelines for the design of stable channels, the protection of steep slopes and overland surfaces, and the stabilization of blowing soil. The difficulty in translating research results into engineering design criteria can be traced directly to a lack of fundamental knowledge concerning the effects of essential physical, chemical and biological factors which regulate the respective erosion processes.

The erodibility of wind-blown soils is determined almost completely by the physical properties of size and weight. In general, soils occurring in arid, sparsely vegetated regions where wind velocities exceed 10 miles per hour at the ground surface will be highly erodible if more than one-third of the particles are less than 1mm in diameter.

The erodibility of soils by water is complicated by the existance of electro-chemical bonds between particles comprising the clay fraction. The inherent complexity of these factors restricts the utility of simple erodibility indices as plasticity index. On the other hand, while a number of erodibility indices offer the advantage of improved reliability, their corresponding complexity renders field application difficult. Of those indicators examined, the erodibility K-factor in the Universal soil loss equation appears to have the most promise for effective use in predicting erodibility.

Because primary Air Force erosion hazards develop largely in response to construction practices on unstable soils, the following principles of erosion control adopted by the Northern Virginia Soil and Water Conservation District (Ref 13) for developing urban regions are especially applicable.

(1) Where feasible, natural vegetation should be retained in place and protected from construction damage.

(2) The development plan should be designed to fit local variations in soil and topography in such a way that the ensuing erosion hazard is minimized.

(3) Both the areal extent and the time of exposure to erosive agents should be minimized during development and construction phases.

(4) Temporary ditches, dikes, vegetation, and mulching should be employed to protect critical soil areas during construction.

(5) Existing drainage facilities should be expanded or modified to convey high peak flows and runoff volumes resulting from disturbed soil and surface conditions both during and after construction.

(6) Sediment basins (debris basins, desilting basins, or silt traps) should be installed to remove increased silt loads from the tributary system draining the construction area.

(7) Permanent vegetation and erosion control structures should be installed as quickly as possible during construction in order to arrest the erosion process at its source.

A similar set of control principles can be identified for the control of wind erosion. The emphasis in either case centers on the shifting of construction priorities to conserve soil cover where possible and to plan for increased soil losses resulting from soil disturbances as an integral phase of the engineering construction operation.

With respect to sediment reduction in urban areas, research into construction techniques has been suggested (Ref 14) to determine the feasibility of:

(1) Timing the period of major earth moving to coincide with low erosion periods;

(2) Installing permanent drainage systems early in the construction schedule to provide a more stable channel downstream from the construction zone;

(3) Installing temporary conveyance structures to carry surface runoff away from steep construction slopes which are susceptible to gully erosion; and

(4) Building storage basins for trapping sediment during construction which can be converted to storm water impoundment structures after construction is completed.

While these suggestions are directed at the alleviation of soil erosion in developing urban regions, they apply with equal validity to the erosion hazards induced by construction operations carried out on the typical Air Force base in this country. In the case of overseas bases, the consideration of construction timing to reduce erosion is constrained by the higher need for efficient base operations in minimum possible time. However, even in the case of expedient construction practices in combat zones, the question of construction priorities and the role of erosion control should be examined.

Before any attempt to evaluate the feasibility of the previously described Air Base construction alternatives can be made, three

intermediate objectives must be met. First, in order to plan for the optimal use of Air Force lands, it is necessary to establish a reliable erodibility index which can be used to delineate areas of highly erodible soils. Because of its wide application to numerous reference soils, the soil erodibility K-factor in the Universal soil loss equation is recommended for possible incorporation in current Air Force land management procedures. Such an index could be used in locating sediment sources by plotting iso-erodibility factor contours. The K-factor and the Universal soil loss equation could also be applied to the problem of predicting sediment yields deriving from surface soils in construction zones. This information is essential to the design of debris basins for the reduction of sediment loads at downstream points.

The second intermediate area of need concerns the physical-chemical properties of the subsoil which determine its resistance to erosion by water (primarily). There is insufficient knowledge concerning the cohesiveness, the permeability, the particle size distribution, the mineral composition, and the exchange capacity of subsoils (Ref 14). In addition, the cohesive properties of subsoils must be related to the type and magnitude of disturbing influences which can be specified as a function of the specific construction practices employed at a given site. The goal is thus to obtain a soil loss equation applicable to subsoils in construction zones when known methods of construction are employed. Such an equation would then be completely analogous to the present Universal soil loss equation for agricultural lands.

The third intermediate objective is for improved practices of estimating surface runoff from small catchment areas comprising an Air Base construction area. The hydraulics of small watershed runoff is complicated by the fact that intense rainfalls produce overland flow which is unsteady and non-uniform. Various numerical methods of estimating surface runoff have been investigated by many universities and by various government agencies at the Federal and State levels. It is suggested that, through cooperative arrangements, the Air Force might readily incorporate improved methods of runoff estimation in its existing land management practices.

Cooperative arrangements to focus existing and expected erosion investigations upon the critical needs of the Defense Department agencies should be made with the Agricultural Research Service and the State Agricultural Experiment Stations to focus upon soil erodibility and structural stability studies, and engineering interpretations of soil properties, peculiar to Air Base problems, especially in critical wind erosion situations. These studies could help advance planning staffs in the selection of new Air Bases here and overseas, as well as regular operating bases. An arrangement of this type should also be worked out with the Soil Conservation Service and the State Agricultural Experiment Stations to focus on

the most effective plants and their fertilizer requirements for erosion control, scenic beauty, and maintenance of Federal installations. These plants can be drawn from worldwide sources and catalogued to fit any combination of climate, soil, slope, and land use.

The following list is the specific recommendations by Water Resources Engineers Inc. for Air Force erosion control research.

(1) Determine the erodibility of Air Force base soils and subsoils by means of laboratory analyses based on:

(a) Established soil erodibility indices, such as the K-factor in the ARS soil loss equation;

(b) New indices of soil erodibility developed in laboratory examination of aggregate size and stability. The review conducted herein leads to the conclusion that existing erodibility indices, including engineering properties of soils, need further refinement prior to their application to Air Force lands.

(2) Develop a soil loss prediction technique based on existing equations, such as the ARS soil loss equation, and the application of a mathematical model for surface runoff and erosion.

(3) Develop a simplified method of field measurement for selected soil and subsoil erodibility parameters. An extension of the field work would include the mapping of soil erodibility to delineate highly erodible soils and potential sediment sources.

(4) Establish the feasibility of modifying current Air Force construction practices to include the reduction of soil losses incurred during major construction as a result of subsequent wind and water erosion.

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